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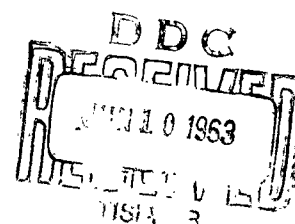
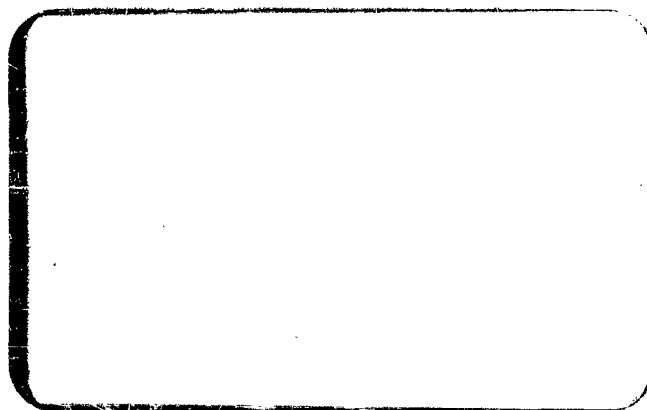
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ISTITUTO SPERIMENTALE DEI
METALLI LEGGERI

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RAPPORTO N°

12.038/6301.102

OGGETTO: **ANODIC METHOD FOR THE STUDY OF
STRESS CORROSION OF ALUMINIUM-
MAGNESIUM ALLOYS**
(Research Contract DA-91-591-
EUC 2067)

Richiesto da: **European Research Office
Frankfurt/Main**

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ISTITUTO SPERIMENTALE DEI METALLI LEGGERI

(prof. C. Panseri, direttore)

Milano, li

29 January 1968

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ISTITUTO SPERIMENTALE DEI METALLI LEGGERI

RAPPORTO N.°

12.038/6301.102

DESCRIPTOR: ANODIC METHOD FOR THE STUDY OF STRESS
CORROSION OF ALUMINIUM-MAGNESIUM ALLOYS
(Research Contract DA-91-591-EUC 2067)

NOVATA: 29 January 1963

1) Purpose of the Report

As already mentioned in the preceding report (No.11.777/6211.036), the second part of the program we agreed with the European Research Office on the above subject, concerned the evaluation of the selectivity of the method in comparison with that of the other traditional methods.

Such comparison was to be based on checking of the possibilities offered by the method under examination and by other methods, to show the influence, already widely known, of some of the principal factors governing the stress corrosion of light alloys.

A first series of tests carried out with the anodic method on some materials of industrial production having varying compositions and structural states, had already made it possible to establish that the method resulted particularly sensitive to the various factors examined (technological conditions of preparation of the material, degree of work hardening, sensitising treatment).

A much wider series of tests has now been undertaken on the influence of these factors, submitting to the anodic test and other types of tests, nume-

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rous materials in different structural states obtained by suitable treatments, all from the same AG 5 alloy rolled section, produced industrially.

In the present report are given the results of the above series of tests.

2) Description of the Tests

The factors chosen for evaluation of the selectivity of the anodic method compared to that of the other methods under examination were as follows:

- a) conditions of annealing preceding the last rolling;
- b) final degree of work hardening;
- c) conditions of sensitising treatment.

In particular, as far as the influence of annealing is concerned, three types of treatment were experimented. They were as follows:

- industrial type of annealing at 400°C for 2 hours with furnace cooling to 200°C in about 8 hours;
- industrial type of annealing set up in France by some authors (1), consisting of heating to 400°C for 2 hours, followed by air cooling then further heating to 240°C for 24 hours and air cooling;
- annealing at 320°C for 4 hours, with slow cooling by degrees for a total of 68 hours (step-annealing).

For simplicity, we will distinguish the three types of annealing by the signs I (industrial annealing), F (French industrial annealing), G (step-annealing).

For the influence of the degree of work hardening, the states H10 and H25, both obtained by rolling after annealing, were experimented with each of the above three annealing treatments.

The influence of sensitising was evaluated using two commonly adopted types of treatment, one of which consisted in heating to 150°C for 16 hours (A15/16) and the other, in heating to 100°C for 3 days (A10/72).

As mentioned, the influence of the above factors on the stress corrosion of Al-Mg alloys is already known in a general way.

For example, it is known that the rate of cooling after the last annealing determines the effects of the susceptibility to stress corrosion of such alloys after sensitising and that the degree of susceptibility induced by sensitising in a material not properly annealed (with insufficiently slow cooling) is tied to the final degree of work hardening of the material.

The influence of the above factors, widely studied by us (2,3) and by others (4) was, however, shown for the most part with the help of traditional laboratory tests based either on the determination of the breaking time or on the evaluation of the loss of weight or decrease in thickness.

Since, in most of the cases, comparative tests were not carried out in the same material without mechanical stress, it was not possible to evaluate separately the behaviour under corrosion and stress corrosion of the material in relation to the above factors.

However, it seemed interesting to check if the anodic method and the relative values of the susceptibility indices used in it would permit the carrying out of a more accurate evaluation of the influence of these factors.

For reasons of time, as methods to be set up in comparison with the anodic method, were chosen two

sufficiently rapid methods both using a saline acid solution for HCl but with different means of application of the stress.

One was a Brenner type of test (fig.1) and made use of specimens under bending stress at constant load, while for the other were used specimens of the same type as those used for the anodic test, under tensile stress with the same apparatus at constant load used for the above test.

Further particulars about the carrying out of the various tests will be described herein.

3) Preparation of Samples

The material used for the preparation of the entire series of samples was a rolled section, industrially produced, of alloy AG 5 UNI 3576 in H10 state, 1000 X 1500 X 2.5 mm in size.

The composition and mechanical characteristics of this material in the state as supplied are reported in table I and II.

To guarantee the complete recrystallisation of the material in the three annealing treatments planned, it was previously brought by rolling to state H25.

From this rolled section were cut three crop ends of 500 X 1000 mm which, suitably divided, were given the three annealing treatments previously described. Each of the three treatments was effected contemporarily on all parts of each crop end.

The cooling curves relating to the industrial type annealing and to the step-annealing, are illustrated respectively in the diagrams of Figs. 2-3.

One half of each of the three crop ends divided in to various parts, was brought, after annealing, to state H10 and the other half to state H25.

Each of the various parts cut from each crop end in the two different states was then further divided into three parts and on two of these were effected the two sensitising treatments planned (A15/16 and A10/72). The sensitising treatment was also carried out contemporarily on all the parts out from the same crop end or with the same annealing, in the two differing states.

In total, 18 types of material were obtained. From each was then cut on the transverse, two proportionally short samples with width of the gauge length equal to 10 mm, for the check of the mechanical characteristics (cfr. Tab. III).

From each of the materials submitted to the two sensitising treatments were then cut 14 samples of the kind illustrated in Fig. 4, for the anodic test and for the test in saline acid solution, and 3 samples of 220 X 20 mm for the Brenner type test.

From each of the materials not given the sensitising treatment, were cut only 8 samples for the anodic test. In fact, the other tests were carried out only on the various sensitised materials, this for reasons herein described.

All the samples for the anodic test and the test in saline acid solution were partially protected with a mixture of paraffin and fertene, as indicated in fig. 4.

Also the samples for the Brenner test were protected by the same type of product, in correspondance

with the line of separation of the air and liquid.

4) Structural Examination

On a test specimen cut from each of the 18 materials used in our tests, the metallographic examination was carried out corresponding to a transverse section as compared to the final direction of rolling.

It was found that, without sensitising, the microstructural characteristics of the samples which had been given the two annealings I (Figs. 5a-6a) and F (Figs. 7a-8a), resulted fully comparable with those in the corresponding work hardened states, whether for the distribution of the inter-metallic compounds or for the entity and form of the reprecipitate of Mg_2Al_3 present in all four samples in very limited quantities and in a discontinuous form, localised mainly at the grain boundaries.

For the material submitted to step-annealing (G), the metallographic examination made it possible to ascertain that this was considerably different from the previous ones, as far as quantity and the modality of distribution of Mg_2Al_3 compound within the matrix of solid solution was concerned.

This material in fact, whether in state H10 or H25 (Figs. 9a-10a) is noticeable for a more marked and general puntiform reprecipitate compared to the other materials. This is due to the fact that step-annealing entails a prolonged stay of the material at temperatures very close to 200°C; in fact these temperatures particularly favour the expulsion of Mg_2Al_3 compound which reprecipitates at the boundaries and inside the grain in the form of larger sized globules.

As for the micrographic characteristics of the materials after the two different sensitising treatments, it is observed that after the two different sensitising treatments, the samples I and F, in state H10 (Figs. 5 and 7) and in state H25 (Figs. 6 and 8) present a reprecipitation more or less continuous at the grain boundaries. The difference between them is essentially one of quantity of reprecipitate, which results more noticeable in the samples given sensitising treatment according to A15/16 compared to those with sensitising treatment according to A10/72 (Fig. 11).

This difference, obvious enough in state H10, tends to be less evident in the material at H25, by reason of the effect of the greater degree of hardening in the rolled sections.

The samples relative to material G (step-annealing), already noted for the rather marked reprecipitation before sensitising treatment, are clearly different in all the states of work hardening from the rolled sections I and F.

In fact, all the samples G sensitized A15/16 (Figs. 9b, 10b), A10/72 (Figs. 9c-10c) are noticeable for their considerable reprecipitation, most evident in state H25, of Mg_2Al_3 in globular form and discontinuous at the boundaries and inside of the grains.

The two different sensitising treatments have not apparently determined substantial differences as far as the quantity of reprecipitate is concerned in the H25 states (Fig. 10).

Instead, in state H10, the sensitising A15/16 has brought about the expulsion of Mg_2Al_3 which is slightly greater compared to state A10/72 (Fig. 9).

5) Stress corrosion tests

The stress corrosion tests were, definitively, as follows:

- a) test with anodic current in a neutral solution;
- b) test in saline acid solution without current and with the same apparatus as used in the anodic test;
- c) Brenner type test in saline acid solution.

As already mentioned, the anodic test was carried out on all the materials, while for the other two types of test, only the materials sensitised with the two treatments A15/16 and A10/72 were used in the experiments. The satisfactory behaviour of all the unsensitised materials in the anodic test, i.e. their nearly complete absence of susceptibility to stress corrosion, made it superfluous to these materials with the other two types of test.

a) Anodic test

For this test eight test samples, ISML model PDC 37 (fig. 4) were used for each type of material. Two test samples were used for the check of the initial mechanical characteristics (cfr. Table IV). Six samples were given the anodic test, three with mechanical stress and three without mechanical stress.

The test was carried out with the apparatus and in the conditions previously used and fully described in a preceding report (cfr. 11.535/6207.104). The mechanical stress induced in the samples was equal to 75% of the yield strength. The electrolyte was a solution of NaCl 5,75% with a pH between 5,6-5,8 and was continually renewed.

The density of current used was 6 mA/cm^2 .

On breaking of one or more of the mechanically stress

ed samples, a corresponding number of unstressed samples was taken out, and these were given a check for residual tensile strength (R_c).

On the basis of this check, the susceptibility to stress corrosion index ($\frac{\Delta R_t}{\Delta R}$) was calculated by the Jones method, according to the formula:

$$\frac{\Delta R_t}{\Delta R} = \frac{R_c - 0.75 s_{0.2}}{R - 0.75 s_{0.2}}$$

The breaking times and susceptibility indices for each type of material are reported in tab.V.

b) Test in saline acid solution

As mentioned, the test was carried out with the same apparatus used for the anodic test but without current and in a saline acid solution. In this test also, mechanically stressed and unstressed test samples were used, so that the susceptibility to stress corrosion indices could be calculated.

Six test samples of the same type as used in the anodic test (Fig.4) were utilized; three with mechanical stress and three without.

The electrolyte was a solution of NaCl 3% + HCl 1% with pH = 1.5. The method of carrying out the test, apart from the application of current, was the same as used for the anodic test. The mechanical stress induced in the samples was equal to 75% of the yield strength and the calculation of the indices was made according to Jones formula, already given.

The breaking times and index values obtained for each type of material in the sensitised state are illustrated in tab. VI.

c) Brenner type test

The test carried out by us has been described as the Brenner type because, although it made use of the same type of test samples (stressed to bending) and of the same apparatus utilized in the actual Brenner test (6), it was substantially different in the means of applications of the stress.

The original conception of the Brenner test, which appears in specification DIN 5098 (6), is in effect, a test at constant strain which prescribed a determined deformation of the material for a determined thickness.

Since, in our tests, we had to compare materials of different thickness and with varying yield strength, and since, for comparison with the other two kinds of test, we had to stress all the materials up to 75% of the yield strength, the above test could not be used in the original and was thus transformed into a test at constant load that would guarantee that the same stress would be induced in the various materials.

This was obtained by determining for each material of different thickness and having different yield strength, the bending moment which will induce an initial stress equal to 75% of the yield strength in an area of the sample included in the part exposed to the action of the liquid.

For simplicity, the load application was made by suitably varying the angle of the lever arm so as to obtain the initial horizontality of the arm for all the materials.

This enabled valuation to be made, in the case of non-breaking of the test sample, of the yield of the material by determining the time corresponding to that of the arrival of the sample at the edge of the recipient.

The electrolyte was a solution of NaCl 3% + HCl 1% at pH 1.5, duly controlled and corrected for the entire duration of the test.

The breaking time values or the values of times set as limits for the test for samples that did not break, are reported in table VII.

6) Results

Let us examine separately the results obtained from the three tests described above.

a) Anodic Test

It is seen, above all (cjr. table V) that without sensitising, no difference in behaviour is found between the materials given the three different annealing treatments, whether in state H10 or in state H25.

The breaking times relating to each are, in fact, very nearly identical and the index values indicate, in all cases, a complete lack of susceptibility to stress corrosion.

There is found only a certain influence of the degree of work hardening on the life of the material. In fact, all the test samples in state H25 underwent breaking in a shorter period of time than did those at state H10.

A clear influence of the annealing treatment was found instead, in the above materials after heat sensitising treatment.

While the materials with annealings I and F presented, in all cases, a more or less high susceptibility to stress corrosion, that with step-annealing (G) showed practically no susceptibility to stress corrosion. Also the breaking times relating to the first two materials (I and F) were, in all cases, notably shorter than those of material G.

As for the comparison between the two annealing treatment I and F, it is seen that, for equal degree of work hardening and heat sensitising treatment, both the breaking times and the index values indicate that the behaviour of material F is slightly better compared to material I.

Satisfactory accordance between the breaking time values and those of the indices is found also as far as the influence of the degree of work hardening is concerned.

At the same annealing treatment and sensitising, all the materials in H25 state undergo breaking after a relatively short time and show a correspondingly higher susceptibility index.

A slight difference between the two criteria of evaluation (breaking times and indices) is found as regards the influence of the sensitising treatment.

While for the same kind of material, the breaking times relative to the two different sensitising treatments are nearly identical, the index values result higher, even though only slightly, for the A10/12 treatment, as compared to A15/16 treatment.

b) Test in saline acid solution

It is seen, above all, (cfr. table VI) as already encountered in the anodic test, a clear difference between the two materials I and F and the material G.

Also in this case, it is observed that the first two materials show a more or less high susceptibility to stress corrosion, while material G shows almost no susceptibility.

It is noted that also in this test, the material F, at equal degree of work hardening and sensitising treatment, shows, in most cases, a slightly better behaviour of the material I, both on the basis of breaking times

and index values.

A part from the influence of the annealing treatment for which, as already mentioned, is found a good agreement between the two above mentioned criteria of evaluation, the influence of the other factors under examination, is notably different, depending on whether it is evaluated on the basis of breaking times or of index values.

In fact, it is seen that the index values do not reveal a noticeable influence of sensitising treatment for material at the same state and that for both sensitising treatments, the influence of the degree of work hardening was comparable.

In particular, the susceptibility indices are even greater for the materials in state H25 than for the materials at state H10 and the two respective values are, a part from some exceptions, almost exactly the same for the two different sensitising treatments.

On the basis of breaking times, however, is found a clear influence of the sensitising treatment, this in turn bound up with the degree of work hardening of the material.

In particular, for example, while at state H25, the breaking times of the materials sensitised A10/72 are only slightly more than the corresponding values for treatment A15/16, at state H10 this difference is very noticeable. In such case, the breaking times are 8-9 hours for treatment A15/16, and 30-40 hours for treatment A10/72.

As a consequence, also the influence of the degree of hardening manifests itself in a noticeably different

measure for the two sensitising treatment and is especially strong in the materials sensitised A10/72.

Thus, the breaking times are even less for the same sensitising for the materials at H25 than for the materials at H10.

The clear difference in behaviour between the two materials in state H10 sensitised A15/16 and A10/72 occurs, however, only with the two materials that are susceptible to stress corrosion, i.e. with annealing I and F. For material G the influence of sensitising on the breaking times is very small even for state H10, for which also the influence of degree of work hardening results completely analogous for the two sensitising treatments. In this case also, however, all the materials in state H25 undergo breaking in a relatively shorter time than do the corresponding materials in state H10.

c) Brenner type test

This test also, like the two preceding tests, has revealed above all, a considerable difference in behaviour between the two materials I and F and material G.

While no breaking of the test samples occurred with material G in states H10 and H25 and for both sensitising treatments, with materials I and F, there was breaking of the samples in most cases.

Contrary to what was found in the preceding tests, no difference in behaviour was shown between the two annealing treatments I and F.

A clear influence of sensitising treatment, bound in turn to the degree of work hardening was found also for this test, as for the tests in the saline acid solution.

Breaking of the test samples took place, in fact, for all the materials sensitised A15/16, both in state H10

and in state H25, while for the materials sensitised A10/72, breaking takes place only in the samples of material in state H25.

It should be noted that, while for state A15/16 no influence of the degree of work hardening is found (the breaking times are almost identical for the two different states), for the material sensitised A10/72, there is a definite difference in the behaviour of the two materials H10 and H25. Those in state H25 undergo breaking after 20-30 hours while those in state H10 do not break after 60-70 hours.

As far as material G is concerned, although, as already seen, no breaking of the test samples was found, comparison between the times corresponding to those at which the yielding of the material took place, indicates a slight influence of the degree of work hardening and no influence of the sensitising treatment.

Also in this case, however, the materials in state H25 undergo breaking in a shorter time than does that in state H10.

7) Discussion of results

The results of the anodic test are in very close agreement with those obtained in the preceding tests and seem equally reproducible and selective.

In fact, it is furtherly confirmed how important is, regarding the behaviour under stress corrosion of the alloy under examination, the choice of technological conditions of preparation of the material, and how it is possible to obtain, with the correct annealing treatment (with a sufficiently slow cooling rate), a material completely free from stress corrosion.

Also the influence of the degree of work hardening and the differing effect produced by this factor on materials that are susceptible or non susceptible to stress corrosion has been further confirmed.

As for the sensitising treatment most suited to reveal the eventual susceptibility induced in the material by a prolonged stay at high temperature, the anodic test does not show any substantial difference between the two treatment experimented, A 15/16 and A 10/72, even through the second treatment seems to show more clearly the structural instability of the material.

The microstructural test results confirm completely the results obtained in the anodic test.

The clear difference of behaviour between the two materials with annealing I and F and that with G annealing after the sensitising treatment are in good agreement with the different structural characteristics of this last material as compared to the first two.

In fact, the structure of material G, contrary to that of the other two materials, shows all the characteristics that, as is well known, confer an excellent resistance to stress corrosion (globular and discontinuous form of the precipitate at the grain boundaries and presence of this precipitate also at the grain center).

The slightly higher susceptibility induced by the sensitising treatment A 10/72 as compared to treatment A 15/16 for the materials with annealings I and F in state H 10, is also justified by the presence, in the material A 10/72, of a film of reprecipitate slightly thinner at the grain boundary.

As far as the slightly better behaviour of material F is concerned, compared to material I, nothing is observed in the structural characteristics that result completely comparable, for the two materials.

The fact that material F behaves in only a slightly better way than does material I, merits a brief comment.

According to what is held by some writers (1) in fact, the treatment used for materials F should have resulted clearly better as compared to a standard industrial annealing treatment of the type experimented by us (cfr. fig.2).

The purpose of the above treatment was to provoke, with a prolonged stay at a temperature between 220°-250°C, a good heterogeneisation of the material that would reduce the amount and modify the form of the reprecipitate at the grain boundary in the successive sensitising treatment, thus improving resistance to stress corrosion.

In substance, this effect did not take place, as shown in the micrographs of figs. 7-8 and as confirmed by the results of the anodic test.

It is now known that the success of this treatment is governed by an accurate choice of the conditions of the treatment itself (temperature and length of time); which conditions are in turn, bound by the composition and state of the material and in particular by the Mg content.

For the purpose of obtaining a proper treatment of this type it would be necessary a previous set up of the treatment conditions to be used for the alloys of the type under examination (Al 5% Mg) with different Mg content.

It is to be further noted that the results obtained from the above-mentioned experiments were based solely on the corrodibility tests in acid solution with HCl (pH = 1,5) and were not further confirmed by the stress

corrosion tests.

It remains how to compare the results of the anodic test with those of the other two tests in saline acid solution.

It is observed above all that, apart from the clear difference shown by all the tests between the materials I and F and materials G, good agreement is found solely between the anodic test and the test in saline acid solution when is used also for this last, as valuation criterion, the value of the susceptibility indices according to Jones.

In all other cases, there are noticeable differences.

In particular the greatest contrast between the results of the anodic test and those of the other two tests exists for the influence of the sensitising treatment. In the two tests in acid solution, the treatment A 10/72 carried out on the materials in state H 10 seems, in fact, to show a noticeably lower susceptibility of the material to stress corrosion, compared to treatment A 15/16.

For example, the absence of breakages found in the Brenner type test for material H 10 A 10/72 is seen, and also a prolonged life of the same material is noted in the saline acid solution.

These results cannot be clearly interpreted and do not have valid justification from the microstructural examination results.

The fact of having used the index calculations as valuation criterion even for one of the two tests in the acid solution, allows affirmation that the difference of behaviour shown in the two types of test for the two sensitising treatments is to be attributed only to the different corrodibility of the two materials.

The susceptibility indices obtained in the saline acid test do not in fact reveal, in accordance with the anodic test, a diversity of behaviour to stress corrosion, at equal state, between the two sensitised materials A 15/16 and A 10/72.

On the other hand, the identical breaking times in the anodic tests for both the materials at state H 10 with different sensitising, indicates that the different corrodibility of the material A 10/72 is manifested only in the saline acid solution.

The differing corrodibility in the saline acid test between the materials A 15/16 and A 10/72 may be due to the fact that, as is known, in the presence of HCl, the cathode reaction passes from reduction of oxygen to evolution of hydrogen, for which the accelerating effect produced by it on the effects of the intercrystalline corrosion is closely connected to the hydrogen-overpotential of the material.

Since the hydrogen-overpotential is greatly influenced by many factors, connected with the intimate structure of the material, small variations in the microstructural characteristics of the two materials that are not shown up by the metallographic examination, may have clearly differentiated the relative values of the hydrogen-overpotential. This may have thus modified considerably the behaviour of the two materials to corrosion without having necessarily changed the entity of the contribution of the mechanical stress to breaking of the material through stress corrosion.

The susceptibility to stress corrosion indices calculated by us define, in effect, solely the entity of this contribution.

In order to be able to explain in detail the differences

ce in behaviour between the two materials, an accurate examination would be necessary, from the structural point of view by means of the help of an electronic microscope, and from the electrochemical point of view.

This examination would permit a final clarification of the lack of agreement often found in the results obtained in the saline acid solution tests which are very frequently used because of their greater speed, for the check of the stress corrosion of the alloys under examination.

8) Conclusions

The selectivity of the anodic method has been evaluated and compared with that of other two methods in saline acid solution, checking the influence of the following factors on the results given by the three methods: conditions of the annealing treatment; degree of work hardening; sensitising treatment.

The results obtained enable us to conclude that:

- a) The anodic method shows a clear influence of the conditions of the annealing treatment and of the degree of work hardening, in effective agreement with the structural characteristics of the materials and also permits in some cases, differentiation between the various types of treatment not shown by the metallographic examination.
- b) The two sensitising treatments experimented (A 15/16 and A 10/72) are indicated by the anodic method as equivalent to the effects of the valuation of the structural instability of the material.
- c) Comparison with the other two methods experimented, both in a solution of NaCl 3% + HCl 1% but one by mechanical bending stress (Brenner type test) and the

other with mechanical tensile stress, has revealed substantial lack of accord whenever the breaking time of the material is used as criterion of evaluation.

- d) These disaccords are due essentially to the differing mechanism of the corrosive phenomenon in the acid solution (pH 1,5), which may make a clear difference in the behaviour of material whose corrodibility in neutral solution is quite equivalent.
- e) The use of control tests in the absence of mechanical stress and the relative calculation of the susceptibility indices according to Jones, may, however, permit carrying out an evaluation of the behaviour under stress corrosion of material for the most part equal to that used in the anodic test;
- f) Also in this case, the results obtained are less selective than those obtained in the anodic test and need a much longer duration of the test.
- g) However the higher suitability of the anodic method has been confirmed compared to the two methods experimented for the control above quoted.
- h) Finally, the above quoted results and the ones obtained in the preceding tests show clearly the validity of anodic method for the study of stress corrosion of aluminium-magnesium alloys.
- i) For the purpose of completing the checking of such a method, a further series of testings is to be carried out consisting of:
 - comparison tests between the anodic and traditional methods in neutral saline solution;
 - stress-corrosion tests in marine atmosphere on those materials that presented various susceptibility indexes during the anodic test. This will allow

to establish the correlation existing between the above quoted values and the effective resistance to stress-corrosion of materials in natural environment.

- 1) After the checking of the validity of the method, it might be employed for completing the research with the extension to the study of other factors yet uncompletely known or unsufficiently experimented, for instance the influence of small additions of Cu or the effect induced by means of an interrupted annealing treatment of the type already experimented (annealing F) or by a partial annealing treatment of the type H 2 or H 3 used by Alcoa.

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TABLE I - CHEMICAL ANALYSIS OF MATERIAL UNDER EXAMINATION

Elements %	Material	P-AG5 UNI 3576
Cu	0.006	≤ 0.05
Hg	4.78	4.5 ± 5.6
Mn	0.29	0.2 ± 0.4
Fe	0.31	≤ 0.4
Si	0.09	≤ 0.3
Zn	0.014	≤ 0.1
Ti	0.008	≤ 0.1

TABLE II - MECHANICAL PROPERTIES DETERMINED ON MATERIAL UNDER EXAMINATION

Material	Tensile Strength (kg/mm ²)	0.2 Proof- stress S _{0.2} (kg/mm ²)	Elongation A ₅ %	B H N (2.5/62.5/30°) (kg/mm ²)
P-AG5 2.5 mm thick	33.2	23.6	15.7	95
P-AG5 N10 UNI 3576	30 ± 35	24±28	12±18	85 ± 95

TABLE III - MECHANICAL PROPERTIES DETERMINED ON MATERIALS UNDER EXAMINATION

Annealing	Temper	Sensitising Treatment	Tensile Strength R(kg/mm ²)	0.2 Proof-Stress S0.2 (kg/mm ²)	Elongation A ₅ %	B H N (25/62.5/30*) (kg/mm ²)
I	H 10	- - -	31.1	26.8	- -	93
	H 10	aged 150°C/16 h	29.3	16.7	24.4	79
	H 10	aged 100°C/72 h	29.8	17.9	22.8	82
I	H 25	- - -	34.5	27.2	12.0	102
	H 25	aged 150°C/16 h	31.1	19.0	20.4	85
	H 25	aged 100°C/72 h	31.8	20.9	18.6	91
F	H 10	- - -	30.8	23.3	16.6	92
	H 10	aged 150°C/16 h	28.9	16.9	26.2	79
	H 10	aged 100°C/72 h	29.4	17.9	22.4	82
F	H 25	- - -	34.1	27.3	11.6	103
	H 25	aged 150°C/16 h	30.3	18.9	20.4	82
	H 25	aged 100°C/72 h	31.3	21.6	18.6	87
G	H 10	- - -	30.8	22.6	18.6	92
	H 10	aged 150°C/16 h	29.1	15.6	24.4	78
	H 10	aged 100°C/72 h	29.9	17.9	22.4	83
G	H 25	- - -	35.4	28.0	10.8	103
	H 25	aged 150°C/16 h	30.8	19.6	21.2	85
	H 25	aged 100°C/72 h	31.8	21.6	18.7	89
P - AG 5	H 10	UNI 3576	30±35	24±28	12±18	85±95
P - AG 5	H 25	UNI 3586	35±40	30±35	8±13	95±110

TABLE IV - TENSILE STRENGTH AND 0.2 PROOF-STRESS DETERMINED ON THE SPECIMENS ADOPTED
IN THE ANODIC TEST

Annealing	Tempera	Sensitising Treatment	Tensile Strength R(kg/mm ²)	0.2 Proof-Stress S _{0.2} (kg/mm ²)
I	H 10	- - -	31.1	26.8
	H 10	aged 150°C/16 h	28.9	17.8
	H 10	aged 100°C/72 h	29.8	18.7
I	H 25	- - -	35.2	32.2
	H 25	aged 150°C/16 h	30.4	22.6
	H 25	aged 100°C/72 h	31.7	23.8
F	H 10	- - -	30.8	25.4
	H 10	aged 150°C/16 h	28.8	17.2
	H 10	aged 100°C/72 h	29.2	19.3
F	H 25	- - -	34.8	29.6
	H 25	aged 150°C/16 h	30.0	18.2
	H 25	aged 100°C/72 h	30.8	20.9
G	H 10	- - -	31.1	26.0
	H 10	aged 150°C/16 h	28.8	16.9
	H 10	aged 100°C/72 h	29.1	19.3
G	H 25	- - -	34.9	32.0
	H 25	aged 150°C/16 h	30.8	21.0
	H 25	aged 100°C/72 h	31.8	22.5

TABLE V - RESULTS OF ANODIC STRESS-CORROSION TEST

Annealing	Temper	Non aged			Aged 150°C/16 h			Aged 100°C/72 h			
		Break- ing ti- me	Rc (kg/mm ²)	Suscep- tibili- ty in- dex	Break- ing ti- me	Rc (kg/mm ²)	Suscep- tibili- ty in- dex	Break- ing ti- me	Rc (kg/mm ²)	Suscep- tibili- ty in- dex	
I	H 10	32 h 12'	17.6	+ 0.22	3 h 48'	23.5	0.66	5 h 6'	24.3	0.72	
		32 h 12'	17.6	+ 0.22	3 h 18'	23.2	0.64	4 h 24'	26.2	0.88	
		32 h 12'	17.6	+ 0.22	4 h 6'	23.7	0.67	4 h 24'	26.1	0.77	
		Average	32 h 12'	17.6	+ 0.22	3 h 44'	23.4	0.65	4 h 38'	25.5	0.75
	H 25	22 h 42'	22.2	+ 0.17	1 h 24'	27.9	0.82	1 h 24'	29.8	0.87	
		22 h 42'	22.9	+ 0.11	1 h	28.4	0.86	2 h 12'	29.0	0.81	
		22 h 42'	22.8	+ 0.14	1 h 30'	27.5	0.79	1 h 42'	29.7	0.86	
		Average	22 h 42'	22.5	+ 0.14	1 h 18'	27.6	0.82	1 h 46'	29.5	0.84
	F	H 10	30 h 48'	17.7	+ 0.11	3 h 42'	23.5	0.60	6 h 12'	23.6	0.62
			30 h 48'	18.5	+ 0.04	5 h 12'	21.7	0.46	4 h 12'	25.7	0.77
			30 h 48'	18.4	+ 0.05	5 h 30'	21.3	0.57	4 h 12'	25.5	0.75
			Average	30 h 48'	18.2	+0.06	4 h 48'	22.1	0.54	4 h 52'	24.9
H 25		24 h 30'	21.1	+ 0.08	3 h 12'	25.3	0.72	2 h 42'	27.9	0.81	
		24 h 30'	21.3	+ 0.07	3 h 30'	25.0	0.70	3 h 6'	27.4	0.78	
		24 h 30'	21.2	+ 0.08	3 h 12'	25.3	0.72	2 h 12'	27.6	0.81	
		Average	24 h 30'	21.2	+ 0.08	3 h 18'	25.2	0.71	2 h 40'	27.7	0.81
G		H 10	34 h 54'	16.4	+ 0.26	38 h 36'	12.9	0.02	31 h 54'	16.6	0.15
			34 h 54'	16.3	+ 0.27	38 h 36'	12.9	0.02	31 h 54'	16.1	0.15
			34 h 54'	16.6	+ 0.25	38 h 36'	13.0	0.03	39 h 6'	13.2	+ 0.08
			Average	34 h 54'	16.4	+ 0.26	38 h 36'	12.9	0.02	34 h 18'	15.3
	H 25	24 h 36'	22.0	+ 0.18	26 h 42'	17.3	0.11	19 h 6'	21.7	0.33	
		24 h 36'	21.7	+ 0.21	26 h 42'	17.2	0.10	22 h 54'	19.2	0.16	
		24 h 36'	21.7	+ 0.21	26 h 42'	17.0	0.09	21 h 24'	19.3	0.17	
		Average	24 h 36'	21.8	+ 0.20	26 h 42'	17.1	0.10	21 h 8'	20.0	0.22

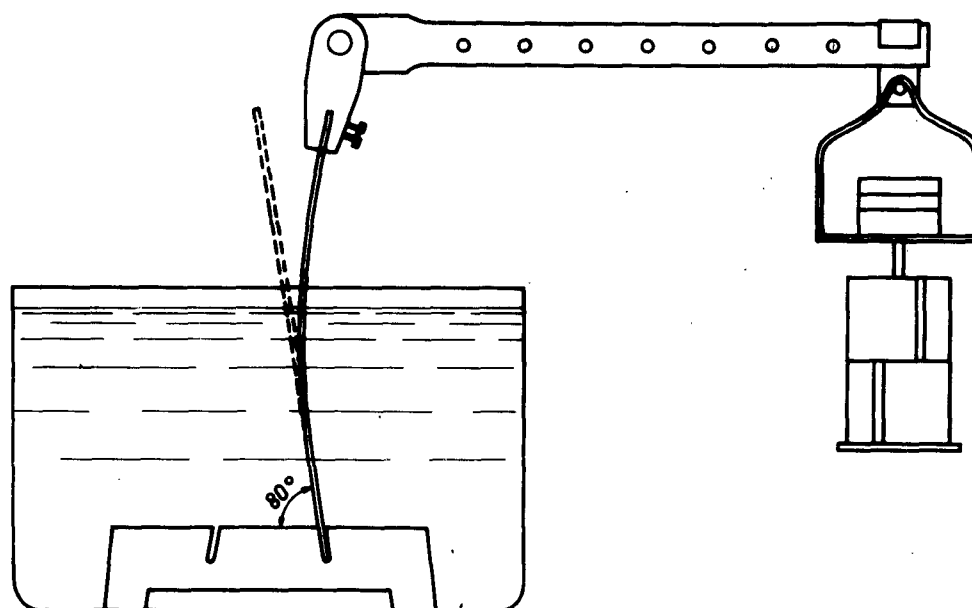
TABLE VI - RESULTS OF STRESS-CORROSION TEST IN 3% NaCl + 1% HCl

Annealing	Temper	Aged 150°C/16 h			Aged 100°C/72 h		
		Breaking Time	R _c (kg/mm ²)	Suscepti- bility Index	Breaking Time	R _c (kg/mm ²)	Suscepti- bility Index
I	H 10	9 h 18'	22.5	0.59	37 h 12'	23.0	0.57
		8 h 48'	22.6	0.60	33 h 30'	22.3	0.53
		-(x)	--	--	25 h	24.8	0.69
	Average	9 h	22.5	0.59	31 h 54'	23.3	0.59
	H 25	4 h 24'	29.2	0.92	6 h 42'	29.6	0.85
		4 h 12'	28.8	0.89	7 h 12'	30.6	0.93
		-(x)	--	--	6 h 12'	30.4	0.91
	Average	4 h 18'	29.0	0.90	6 h 42'	30.2	0.89
F	H 10	7 h 48'	23.5	0.68	41 h 42'	21.8	0.50
		9 h 36'	22.1	0.59	43 h 36'	21.8	0.50
		8 h 42'	23.1	0.57	38 h	20.9	0.54
	Average	8 h 42'	22.9	0.61	41 h 6'	21.5	0.51
	H 25	8 h 12'	23.9	0.63	15 h	26.4	0.71
		6 h 24'	25.8	0.75	9 h 54'	29.0	0.89
		7 h 18'	24.0	0.64	8 h 48'	29.0	0.89
	Average	7 h 18'	24.5	0.67	11 h 14'	28.1	0.83
G	H 10	99 h 36'	16.5	0.24	138 h	11.6	+ 0.19
		128 h 30'	12.6	0	215 h 18'	5.9	+ 0.58
		128 h 48'	14.3	0.11	119 h	14.8	0.03
	Average	119 h 18'	14.4	0.11	157 h 26'	10.7	+ 0.24
	H 25	68 h 42'	17.1	0.09	90 h 12'	17.1	0.02
		67 h 18'	18.4	0.18	91 h 30'	16.8	+ 0.07
		61 h	19.9	0.28	81 h 48'	17.5	0.05
	Average	65 h 40'	18.4	0.18	87 h 50'	17.1	0

(x) Results not available owing to a failure of hour-counter

TABLE VII - RESULTS OF BRENNER TYPE STRESS-CORROSION TEST

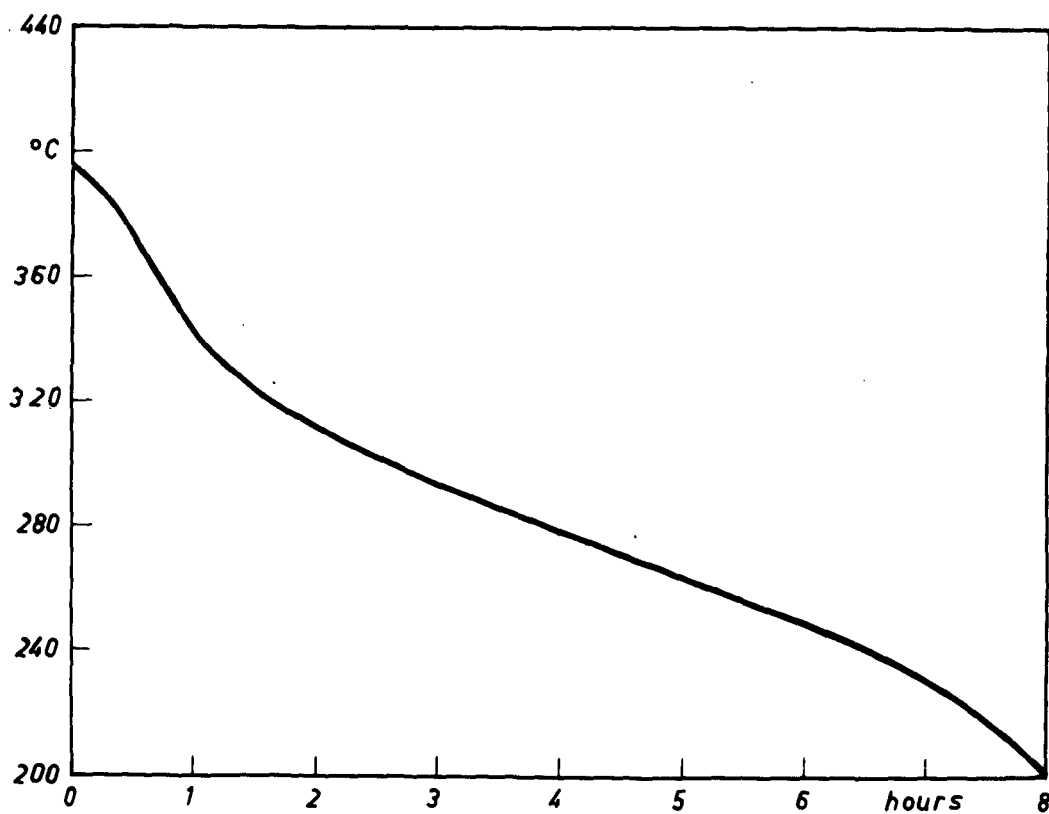
Annealing	Temper	Aged 150°C/16 h		Aged 100°C/72 h	
		Breaking Time	End Time (unbroken specimens)	Breaking Time	End Time (unbroken specimens)
I	H 10	13 h 18'	---	---	62 h 12'
		12 h	---	---	78 h
		12 h 12'	---	---	67 h 30'
		Average	12 h 30'	---	69 h 14'
	H 25	11 h	---	22 h 48'	---
		13 h 54'	---	21 h 30'	---
		12 h 36'	---	17 h 48'	---
		Average	12 h 30'	20 h 42'	---
	F	10 h 48'	---	---	62 h
		12 h 12'	---	---	58 h 12'
		12 h 18'	---	---	65 h 15'
		Average	11 h 46'	---	61 h 49'
G	H 10	---	124 h	---	140 h
		---	95 h	---	101 h
		---	102 h	---	112 h
		Average	107 h	---	117 h 40'
	H 25	---	73 h	---	78 h
		---	83 h	---	73 h 30'
		---	64 h	---	72 h 30'
		Average	73 h 20'	---	74 h 40'



I. S. M. L.

Fig. 1 - Scheme of apparatus employed for the
Brenner type test.

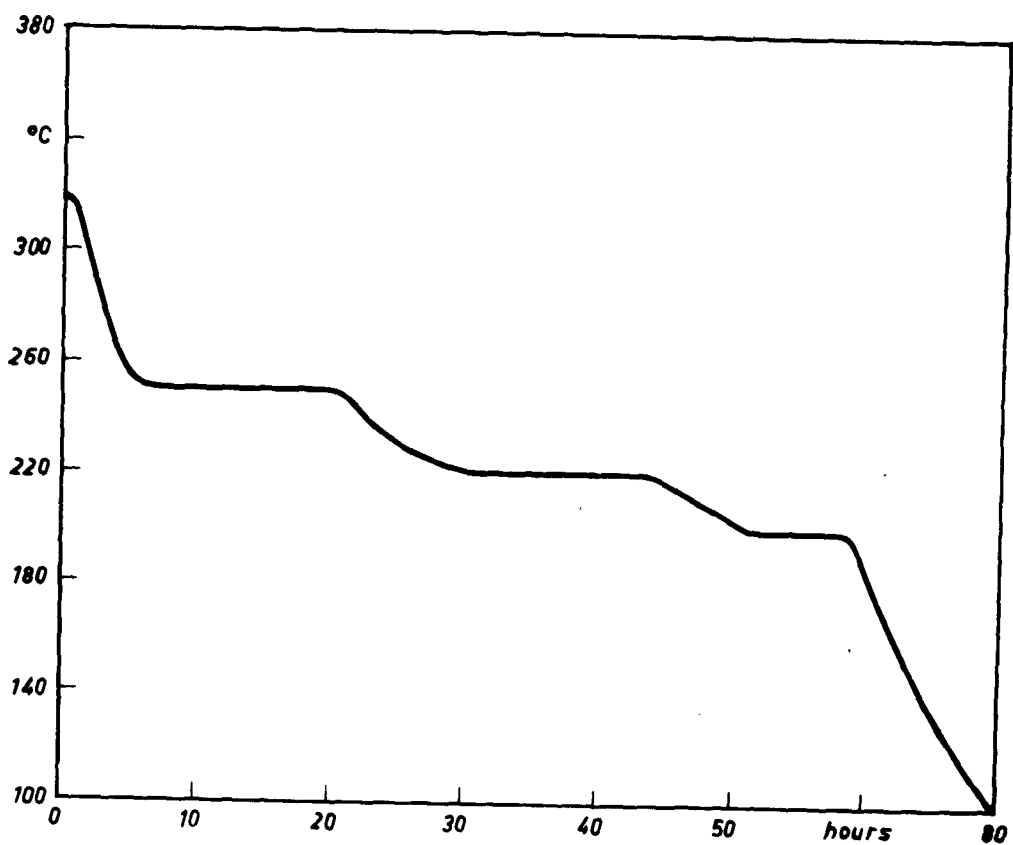
dis. N. 78-63



I.S.M.L.

Fig.2 - Cooling curve relating to the industrial annealing performed on the material under examination

dis. N. 77-63



I.S.M.L.

Fig.3 - Cooling curve relating to the step-annealing performed on the material under examination.

dis. N. 76-63

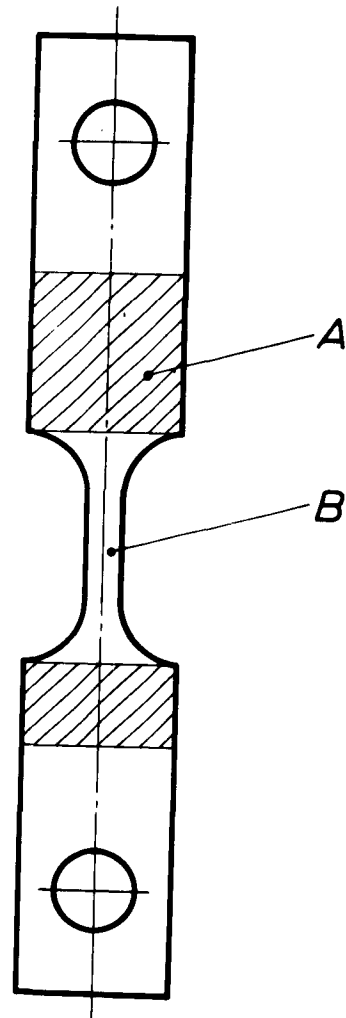


Fig. 4 - Type of specimen adopted in the anodic test:

A = was covering

B = exposed gauge length

(Plate n. 31096/6)



a

b

c

Fig. 5 - Microstructure of material I in temper H10 before (a) and after sensitizing treatment A15/16 (b) and A10/72 (c). Etching: H_3PO_4 40%. Magn. X 500.
(Plates nos. 35.898, 35.899, 35.900)

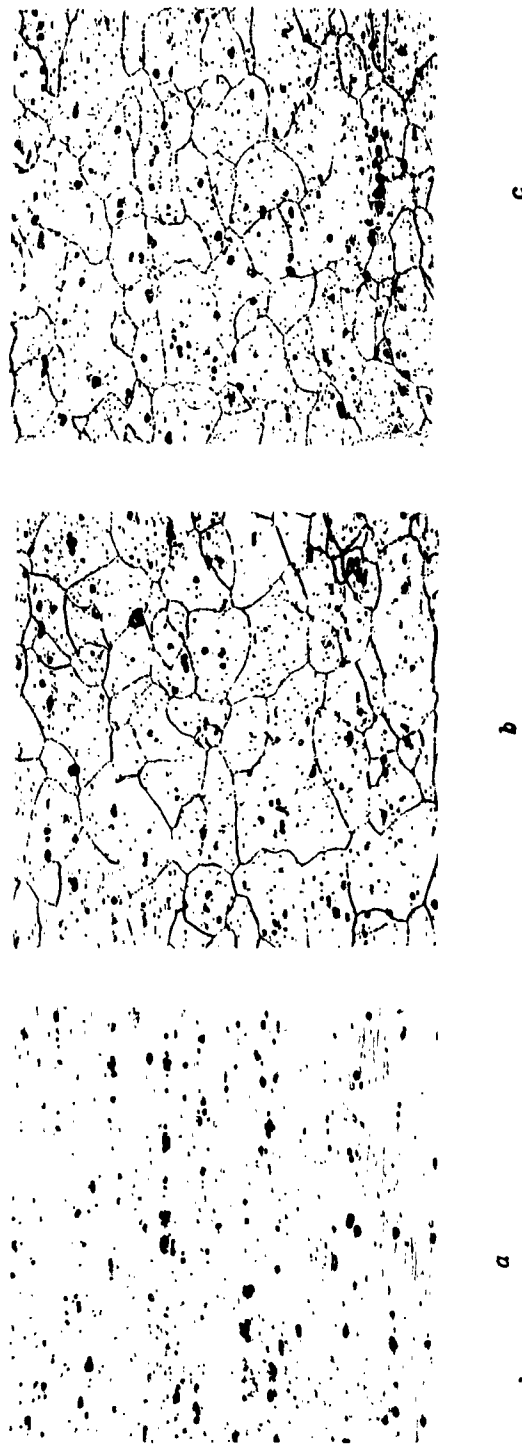


Fig. 6 - Microstructure of material I in temper H25 before (a) and after sensitizing treatment A15/16 (b) and A10/72 (c). Etching: H_3PO_4 40%. Magn. X 500.
(Plates nos. 35.901, 35.902, 35.903)



Fig. 7 - Microstructure of material F in temper H10 before (a) and after sensitizing treatment A15/16 (b) and A10/72 (c). Etching: H_3PO_4 40%. Magn. X 500. (Plates nos. 35.895, 35.896; 35.897)



a b c

Fig. 8 - Microstructure of material F in temper H25 before (a) and after sensitizing treatment A15/16 (b) and A10/72 (c). Etching: H_3PO_4 40%. Magn. X 500. (Plates nos. 35.892, 35.893, 35.894)

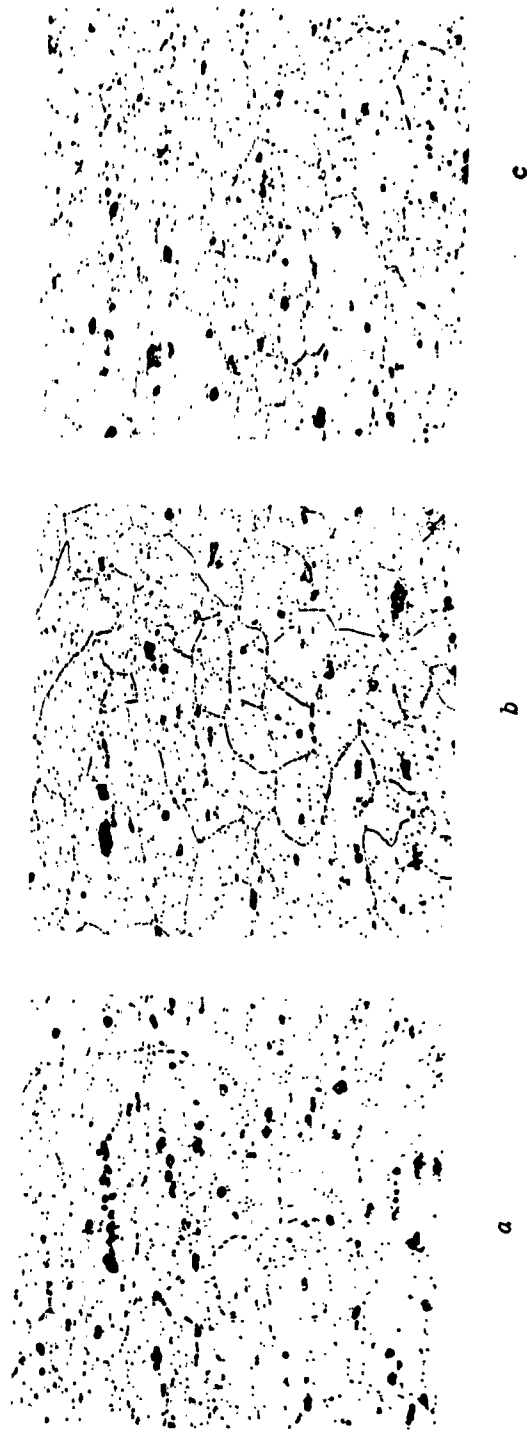


Fig. 9 - Microstructure of material G in temper H10 before (a) and after sensitizing treatment A15/16 (b) and A10/72 (c). Etching: H_3PO_4 40%. Magn. I 500. (Plates nos. 35.889, 35.890, 35.891)

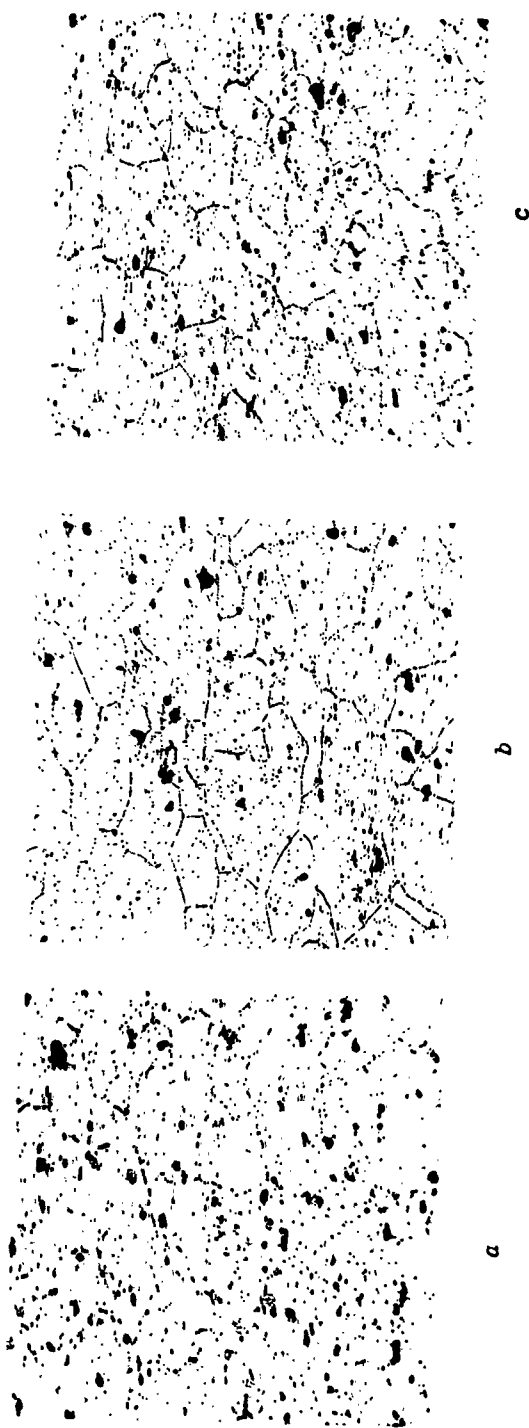


Fig. 10 - Microstructure of material G in temper H25 before (a) and after sensitizing treatment A15/16 (b) and A10/72 (c). Etching: H_3PO_4 40%. Magn. X 500.
(Plates nos. 35.886, 35.887, 35.888)



a

b

Fig. 11 - Microstructure of material F in temper H10 after sensitizing treatment A15/16 (a) and A1C/72 (b). Etching: H_2PC_4 40%. Magn. X 1200.
(Plates nos. 35.864, 35.865)